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DESIGN AND PERFORMANCE EVALUATION OF ACCELERATING POWER BASED FUZZY LOGIC POWER SYSTEM STABILIZER

MOHAMED JALALUDDIN[1], H. V. SAIKUMAR[2] & BANSILAL[3]

[1]Department of Electrical and Electronics Engineering, Vidyavardhaka College of Engineering, Mysore, Karnataka, India

[2]Department of Electrical and Electronics Engineering, The National Institute of Engineering, Mysore, Karnataka, India

ABSTRACT

Small signal oscillations can be effectively damped using power system stabilizers. In this paper Fuzzy Logic Power System Stabilizer (FLPSS) is designed to damp low frequency oscillations and improve the stability of the power system. Speed deviation and accelerating power are taken as inputs to the FLPSS. The rules are framed using if - then format. MatLab and Simulink are used for analysis purpose. The effectiveness of proposed FLPSS is demonstrated by considering Single Machine connected to Infinite Bus system (SMIB). A comparative study of the performance of FLPSS and conventional PSS is carried out.

KEYWORDS: Stability, Low Frequency Oscillations, Conventional PSS, Fuzzy Logic Power System Stabilizer, Supplementary Modulation Controller

INTRODUCTION

With increasing power demand the power system is becoming more complex. Many synchronous generators are working synchronously to meet the power demand. An increase in generator loading or faults in the power system creates small signal oscillations. If the oscillations are not damped the synchronism of power system will be lost. Adequate measures are initiated to damp these oscillations for secure operation of power systems. Power System Stabilizer (PSS) is the most widely used supplementary modulation controller in the generator excitation system to damp low frequency oscillations. The objective of PSS is to provide additional damping torque to the generator rotor in phase with speed deviation. The design of conventional PSS is based on linearized mathematical model. The parameters of conventional PSS are determined at nominal operating point. When the operating point changes the performance of PSS will not be efficient. Researchers opted for more intelligent controls such as fuzzy PSS, ANN based PSS etc, which are model free [1].

The stability of a power system can be enhanced by employing fuzzy logic power system stabilizer. Speed deviation and acceleration can be considered as inputs to the fuzzy controller [2,3]. For small signal stability analysis Heffron-Phillip model gives acceptable results. Modified Heffron-Phillip model can be used to design PSS [4]. Depending on number of linguistic variables the rules required to build FLPSS varies. With two input linguistic variables only four rules can be employed to model FLPSS [5].

This paper describes a Fuzzy logic based PSS to damp low frequency oscillations in a power system and improve system stability. Normally speed deviation and acceleration are considered as inputs to the controller. In this paper speed deviation and synthesized accelerating power are considered as inputs to the controller. The synthesized accelerating power

signal has the advantage of eliminating the problem of torsional interactions and improved reliability [6]. The performance of the PSS is evaluated by simulating small disturbance and a three phase fault at the generator terminals separately.

Lotfi Zadeh introduced a mathematical tool to deal with uncertainty in data called fuzzy logic tool. Fuzzy theory provides a systematic procedure to represent linguistic variables such as ‘low’, ‘high’, ‘medium’. The fuzzy logic theory is not a crisp logic; it is based on membership function. It helps us in dealing with uncertainty or ambiguous data. Set membership idea is used in decision making under uncertainty condition. The membership can take a value between ‘0’ and ‘1’. Different types of membership functions like trapezoidal, triangular, sigmoidal, Gaussian etc. can be used for analysis. Based on the requirement and constraint the membership value is decided.

Fuzzy set is represented as

A={(x, a(x))}, x ε X, a(x) = Degree (x ε A)

where xεX: possibility distribution and a(x): membership function.

GENERATOR MODELLING

The Figure 1 shows the single line diagram of a SMIB system.

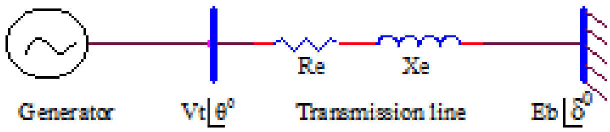


Figure 1: Single Machine Connected To Infinite Bus

Synchronous machine model 1.0 is employed for analysis [6].

The machine equations are:

$$\frac{d\delta}{dt} = \omega_B (S_m - S_{mo}) \tag{1}$$

$$\frac{dS_m}{dt} = \frac{1}{2H}\left[-D(S_m - S_{mo}) + T_m - T_e\right] \tag{2}$$

$$\frac{dE_q^{'}}{dt} = \frac{1}{T_{do}^{'}}\left[-E_q^{'} + (x_d - x_d^{'})i_d + E_{fd}\right] \tag{3}$$

$$\frac{dE_{fd}}{dt} = \frac{1}{T_a}\left[(V_{ref} - V + V_{pss})K_a + E_{fd}\right] \tag{4}$$

$$T_e = E_q^{'} i_q - (x_q - x_d^{'}) i_d i_q \tag{5}$$

$$(V_q + jV_d) = (Z_r + jZ_i)(i_q + ji_d) + (h_1 + jh_2)E_b e^{-j\delta} \tag{6}$$

$$F_1 = (h_1 E_b \cos\delta + h_2 E_b \sin\delta - E_q^{'}) \tag{7}$$

$$F_2 = (h_2 E_b \cos\delta - h_1 E_b \sin\delta) \tag{8}$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} Z^{-1} \end{bmatrix} \begin{bmatrix} F_1 \\ F_2 \end{bmatrix} \tag{9}$$

The synchronous machine is modelled using Matlab and simulink blocks.

CONVENTIONAL POWER SYSTEM STABILIZER

Power system stabilizers are commonly employed to damp low frequency oscillations. PSS produces additional damping torque to the rotor in phase with speed deviation. Figure 2 shows a Conventional PSS (CPSS). CPSS has washout circuit and dynamic compensator. The washout circuit acts as high pass filter. T_w is the wash out time constant, K_s is the PSS gain, T_1 and T_2 are the time constants of the compensator. Speed deviation is fed as input to the compensator and stabilizer output is the modulating signal in the excitation system.

The parameters of CPSS are obtained by employing following steps [6]: (i) For local modes, T_w is selected between 1 to 2 secs. (ii) Gain of PSS is chosen considering the damping of all critical modes under various operating conditions. (iii) T_1 and T_2 are chosen based on the requirement of phase compensation. Compensated phase lag should pass through 90^0 at frequency around 3.5^0. Compensated phase lag should be below 45^0. (iv) Root locus analysis is performed to set the gain of PSS. Root locus plot is obtained as K_s is varied. Optimal PSS gain is chosen such that critical mode has maximum damping ratio. The parameters of CPSS obtained are T_w: 2 secs, K_s: 16, T_1: 0.078 secs and T_2: 0.027secs.

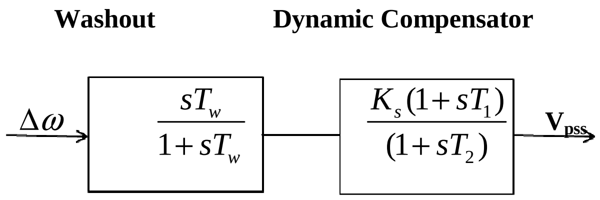


Figure 2: Conventional PSS

FUZYY LOGIC POWER SYSTEM STABILIZER

Fuzzy Logic Controller

Fuzzy controllers are used to build the FLPSS. Figure 3 shows the structure of Fuzzy logic controller (FLC). FLC has four components.

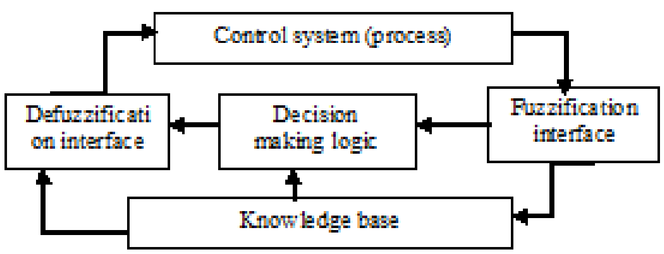


Figure 3: Structure of Fuzzy Logic Controller

- **Fuzzifiction:** The input variables are measured (e.g. speed, acceleration) and converted to suitable linguistic variables with suitable membership function. The linguistic variables used are; NB (Negative Big),

NM (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium) and PB (Positive Big).

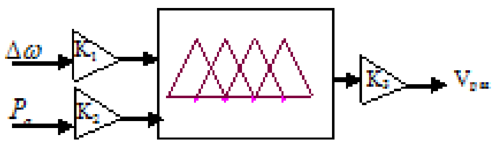
- **Knowledge Base:** The knowledge base has a rule base where fuzzy data manipulation takes place on set of defined rules. Human expertise can be used in framing rules. The set of rules are stored in knowledge base. The rule base used for the fuzzy controller is given in Table 1. For example if speed deviation is NM and accelerating power is Z then output is NM. If speed deviation is PM and accelerating power is PM then output is PM, and so on.
- **Inference Mechanism*:*** Inference mechanism processes the input signals and generates output based on rules.
- **Defuzzification:** The output will be in the format of linguistic variable. In the final stage the linguistic variable are converted to crisp variable.

Table 1: Rule Base of Fuzzy Logic Controller

Speed Deviation	**Accelerating Power**						
	NB	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NM	NS
NM	NB	NM	NM	NM	NS	NS	Z
NS	NB	NM	NM	NM	NS	NS	Z
Z	NM	NS	NS	Z	PS	PS	PM
PS	NS	Z	Z	PS	PS	PM	PM
PM	Z	PS	PS	PM	PM	PM	PB
PB	PS	PM	PM	PB	PB	PB	PB

Fuzzy Logic Power System Stabilizer

Fuzzy logic power system stabilizers contain Fuzzy Logic Controller(FLC) with set of input signals and an output signal. Normally speed deviation and acceleration are considered as input to the controller. In the work presented in this paper speed deviation and accelerating power are given as input to the controller. The inputs are given to fuzzy logic controller through gain blocks K_1 and K_2. The output of FLC is voltage stabilizing signal which is fed to the synchronous machine for damping the oscillation in power system through gain K_3. Figure 4 show the FLPSS employed for the analysis.



Fuzzy Logic Controller

Figure 4: Basic Structure of Fuzzy Logic Power System Stabilizer

The gains K_1, K_2 and K_3 of the controller are tuned manually until the oscillations are damped at quicker rate. The gain values for three phase fault condition after tuning is K_1=4.5, K_2=0.1 and K_3=1.4.

FIS Editor

FLPSS is simulated using FIS editor. The input variables, speed deviation and accelerating power are created with corresponding membership functions. The rules are entered in the rule editor. The FLPSS created is included in the Simulink used to simulate the SMIB system. Figure 5 shows the membership function used for speed deviation.

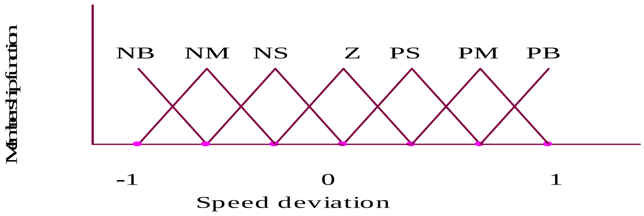


Figure 5: Membership Function for Speed Deviation

SYNTHESIS OF ACCELERATING POWER FOR STABILIZER

The inputs to the PSS can be deviation in rotor velocity, electrical power, accelerating power. By employing accelerating power as stabilizer input the problem of torsional interaction can be eliminated and reliability can be improved [6]. In the proposed work one of the inputs to FLPSS is the synthesized accelerating power (P_{a}). It can be obtained from speed deviation and electrical power as shown in Figure 6 [6].

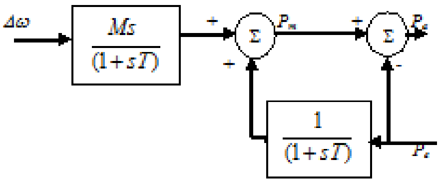


Figure 6: Synthesis of Accelerating Power Signal

M is the inertia constant of machine. The value of T is obtained by tuning FLPSS to damp the oscillations quickly. The value of T after tuning is 0.01 secs.

RESULTS AND DISCUSSIONS

The performance of the SMIB system is analyzed for the following two cases.

Five Percent Step Increase in V_{ref}

SMIB is analyzed for a five percent rise in V_{ref}. The step increase in V_{ref} occurs at 1 sec. The results obtained from the system without PSS, with fuzzy PSS and CPSS are illustrated.

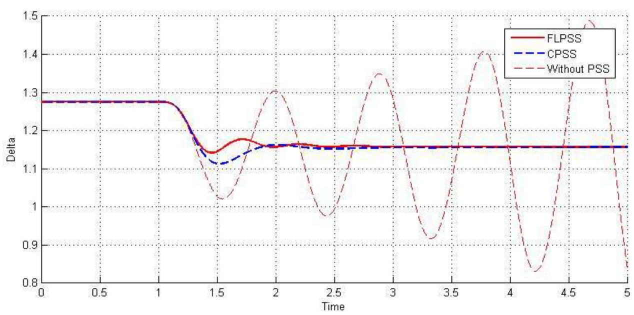


Figure 7: Plot of Delta without PSS, with FLPSS and CPSS for Five Percent Rise in V_{ref}

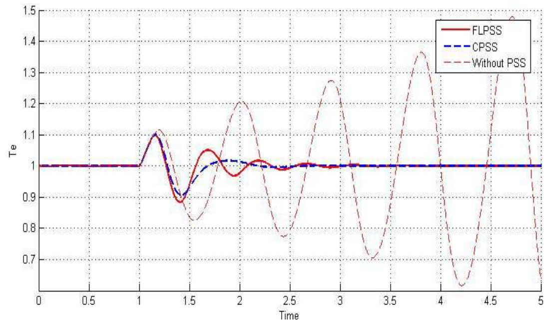


Figure 8: Plot of T_e without PSS, with FLPSS and CPSS for Five Percent Rise in V_{ref}

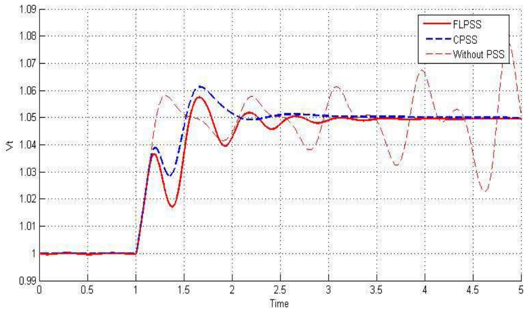


Figure 9: Plot of V_t without PSS, with FLPSS and CPSS for Five Percent Rise in V_{ref}

From the simulation curves obtained for small disturbance, it is observed that the FLPSS performs as effectively as a CPSS does.

Three Phase Fault at Generator Terminal

SMIB is subjected to a three phase fault at the generator terminals. The three phase fault occurs at 1 sec. The fault is cleared within five cycles. The results obtained from the system without PSS, with CPSS and fuzzy PSS are tabulated.

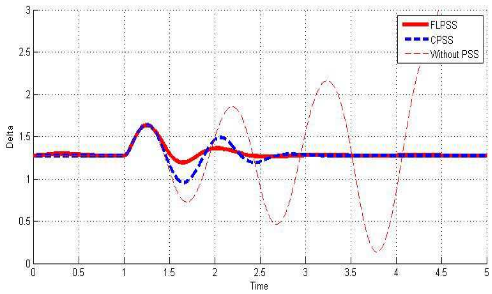


Figure 10: Plot of Delta without PSS, with FLPSS and CPSS for a Three Phase Fault

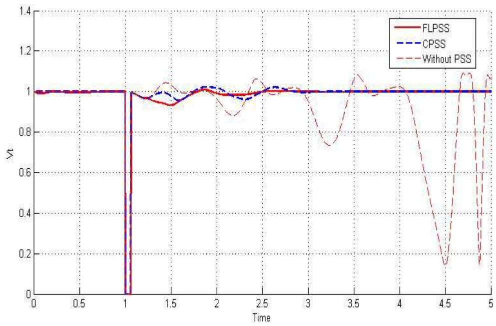


Figure 11: Plot of V_t without PSS, with FLPSS and CPSS for a Three Phase Fault

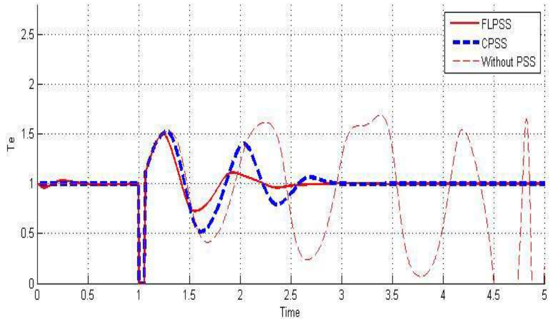


Figure 12: Plot of T_e without PSS, FLPSS and CPSS for a Three Phase Fault

The settling time for delta is lesser with fuzzy PSS. It settles down at 2.5 secs with FLPSS whereas with CPSS it takes 3.2 secs. The settling time for T_e with FLPSS is 2.4 secs whereas with CPSS it is 3.0 secs. It is seen from the above results that the FLPSS is very effective in providing adequate damping under 3-phase faults also.

CONCLUSIONS

In this paper the performance of fuzzy logic PSS with synthesized accelerating power input is compared. Accelerating power is synthesized using speed deviation and electrical power. FLPSS is created using SIMULINK. The designed PSS is validated by carrying out simulation on the nonlinear power system model for two cases (a) five percent step increase in V_{ref}. (b) Three phase fault is simulated at the generator terminals. The impact of CPSS and FLPSS on the system is analyzed. It is observed that the FLPSS is as effective as a CPSS in providing damping to low frequency oscillations. It is also very effective in mitigating oscillations arising out of a large disturbance simulated at the generator terminals.

The only problem that a designer of FLPSS comes across is that the tuning consumes more time. This problem can be overcome by using genetic algorithm.

APPENDIX A

The machine data used for analysis are [6]:

The synchronous machine is connected to infinite bus through external reactance of x_e=0.4 pu, P_g=1.0, $_{Vt}$=1.0, E_b=1.0

The machine data are: x_q=1.55, $x_d^{'}$=0.32, $T_{do}^{'}$=6.0, H=5, D=0, f_b=50 Hz, K_E=200, T_E=0.05, Fault occurs on generator terminal and the fault is cleared after 4 cycles. Limits on PSS output are +/- 0.05 pu and limit on E_{fd} =+/- 6.0 pu.

APPENDIX B

Abbreviations used in equations:

S_m =Slip speed of generator.

S_{mo} =Initial slip speed of generator.

δ= Rotor angle of the generator.

H= Inertia constant of generator.

$T_{do}^{'}$ =open circuit transient time constant.

T_m=Mechanical torque input to generator.

Te=Electrical torque output of generator.

D=Damping factor.

V_{fd} =Field voltage.

E'_q = q-axis component of the transient internal emf.

V_d =d-axis component of generator terminal voltage.

V_q = q-axis component of generator terminal voltage.

$x_d^{'}$ =d-axis transient reactance of generator.

x_d= d-axis steady state reactance.

$x_q^{'}$ =q-axis transient reactance of generator.

i_d =d-axis current.

V_{fd} = q-axis current.

V_{pss}= Power system stabilizer output.

K_a = Gain of power system stabilizer.

REFERENCES

1. Mahdiyeh ESLAMI, Hussain Shareef, Azah Mohamed, “Application of artificial intelligent techniques in PSS design: A survey of the state-of-the-art methods”, Przegląd Elektrotechniczny (Electrical Review), ISSN 0033-2097, R. 87 NR 4/2011.
2. E Tejaswita Khobaragade and Amol Barve , “ Enhancement of power system stabiltiy using fuzzy logic controller”, IJPEDS, vol. 2,no. 4,pp. 389"-401,December 2012.
3. CH.S.K.B. Pradeepkumar, V.S.R. Pavan Kumar Neeli, “Enhancement Of Power System Stability Using Fuzzy Logic Based Power System Stabilizer”, International Journal on Engineering Research and Applications(IJERA)”, Vol. 2, Issue4, July-August 2012, pp.1814-1819.
4. Dordla Pratap Hari Krishna et .al , “Design of Power System Stabilizer to improvr small signal stabiltiy by using modified Heffron- Phillips model”, IJEST, vol. 3, no. 6,pp. 4888-4896, June 2011.
5. Vijay kumatr Tayal, J.S Lather, “Digital Simulation of Reduced rule Fuzzy Logic Power System Stabilizer for Analysis of Power system Stability Enhancement” IJCA, vol. 47, no. 7, pp.25-31. June 2012.

6. K.R Padiyar, Power System Dynamics Stability and Control, B.S publication, 2 edition.

7. K. Prasertwong and, N. Mithulananthan, “Conventional and Fuzzy Logic Controllers at Generator Location for Low Frequency Oscillation Damping”, World Academy of Science, Engineering and Technology, 28, 2009, pp. 694-702.

8. A.Padmaja,V.s. vakula, T.Padmavathi and S.V.Padmavathi, “Small Signal Stability Analysis and Artificial Neural Network Stabilizer”, International Journal of Electrcical Engineering and Technology(IJEET), vol. 1, no. 1, May-june 2010, pp. 47-70.

9. K. Pounraj, “Fuzzy Co-ordination Of UPFC for Damping Power System Oscillations”, International Journal of Electrical Engineering and Technology(IJEET), vol. 3, Issue 1,Jan-June 2012, pp. 226-234.

10. Timothy J.Ross, “Fuzzy Logic with engineering applications”, Wiley India Pvt.Ltd.,second edition.